SUMMARY OF THE CHAMONIX 2010 ON RADIATIONS TO ELECTRONICS*

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REVIEW OF CRITICAL RADIATION AREAS FOR LHC ELECTRONICS AND MITIGATION ACTIONS - RADIATION MONITORING AND FIRST RESULTS

The R2E Study Group presentation included a summary of the 2009/2010 activities, as well as the status of possible mitigation options. Based on the expected evolution of LHC intensity and integrated luminosity, an update of the radiation levels in the critical LHC areas was given. The most critical areas were pointed out, emphasizing that even though radiation levels are to be expected low for 2009 operation, the LHC milestone of reaching a 1% of nominal luminosity and 15% of nominal intensity by the end of 2009 could imply first problems in the most critical areas.

During the shutdown 2008/2009 shutdown several improvements for radiation monitoring and their analysis were already put in place by the R2E Study Group. Furthermore, certain shielding improvements (*e.g.*, UJ23/87 and the US85 safe-room) could be implemented before 2009 LHC start-up. These activities were already reported in several LMC meetings, references were given and thus not further described during the presentation.

With respect to monitoring and the radiation field in the LHC critical areas, several new FLUKA calculations were performed. This allows not only for an almost complete summary, but also provides a first analysis for the risk of low-energy neutrons. It was shown that for certain critical areas it is expected to have up to 100-200 times more low-energy neutron fluence as compared to the respective high-energy contribution. With possible failure cross-section ranging from two to three orders below up to, and even exceeding the high-energy one, makes it clear that the risk of low-energy neutrons must not be neglected. Early LHC and CNGS measurements shall further focus on this subject in order to provide a better knowledge during 2010.

The R2E Study Group could further prove the good agreement between FLUKA simulations and observed radiation levels (examples were given for RA/UA63/67 and UJ88/87). What concerns the radiation sensitivity however, the knowledge of expected equipment failure cross sections remains limited. 2009 CNGS tests focusing on LHC tunnel electronics (highest risk of failures), the equipment installed in critical areas mainly consists of components of the shelf (COTS), thus does not allow for a coherent characterisation. The multitude of different equipment and components make it impossible to give reliable estimates for failure cross-sections of all components, or respective failure rates to be expected for certain radiation levels. Early LHC measurements and a 2010 CNGS measurement campaign are suggested in order to provide possible lower or upper failure thresholds, but it must be kept in mind that these can give general indications only. It was further emphasized that only regular monitoring and immediate analysis can allow optimizing envisaged mitigation solutions.

R2E mitigation options range from shielding improvements, relocation possibilities, radiation tolerant design to civil engineering requirements, as well as the study of alternative approaches like changes to the collimation system to super-conducting links. Whereas certain medium-term improvements can be implemented in a direct way (limited cost and time requirements), it was pointed out that for most long-term solutions for critical areas only an intensive consolidation program can lead to sustainable results. In a first detailed analysis, the R2E Study Group compared the various options for each critical area and performed a detailed analysis of their respective requirements, limitations and improvements.

It was shown while shielding can improve the situation in many areas, with increasing luminosity/intensity radiation levels would still exceed expected 'safe' thresholds for most of the areas. In addition, relocation being a possibility for many areas, requiring an important amount of preparation and implementation time, it still leaves certain equipment almost impossible to relocate (*e.g.*, power-converters), as well as faces severe space limitation in certain areas (*e.g.*, P1). For the latter, only re-design, possible super-conducting links or severe civil-engineering can then lead to a long-term solution. Further alternative solutions were analyzed for the collimation areas, where phase-II collimation or a temporary move of the betatron collimation to IR3 was studied. In this respect, it was pointed out that most of the long-term solutions require a combination of mitigation actions in order to minimize the risk of radiation induced electronics failures.

Many of these solutions implying not only high costs, but also important lead and installation times, thus require possibly long shutdown periods. During the discussion it was pointed out that further details are required for essential mitigation decisions to be drawn. A follow-up workshop was proposed for April/May 2010 where all concerned stakeholders are requested to provide the required details and conclusion of their analysis. To give a detailed overview of the R2E project and further clarify these requirements, an extended R2E seminar will be organised, followed by detailed iterations through the R2E Study Group. The result of this workshop shall then

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lead to a planning proposal on how to mitigation LHC radiation induced electronic failures in the long-term.

To reach the above, it was strongly emphasized, that an increased effort must be made available as soon as possible and with respect to all R2E requirements (monitoring, testing, equipment inventory and relocation constraints, integration studies, study of mitigation options, planning requirements, etc…). Mitigation solutions can not be optimized nor fully compared to each other if related resources are not sufficiently freed during the coming months. This requires that respective activities reach a high priority for all concerned departments, groups and sections.

REVIEW OF EXPOSED EQUIPMENT IN THE LHC: A GLOBAL VIEW

An overview of equipment exposed to radiation in critical LHC areas has been presented and the most critical systems are high-lighted with respect to system criticality and operational impact in case of failure, as well as to the expected estimated radiation sensitivity in the different LHC points (see Tables in related Paper). Systems have been tested in terms of:

- Single Events Soft Errors (recoverable)
  - Single Event Upset (SEU)
  - Multiple Bit Upset (MBU)
  - Single Event Transient (SET)
  - Single Event functional Interrupt (SEFI)
- Hard Errors (non recoverable)
  - Single Event Latch-up (SEL)
  - Single Event Gate Rupture (SEGR)
  - Single Event Burn-out (SEB)
- Total Dose
- Displacement damage

Tests have been realized at the CNGS facility where the quantities such as Dose (SiO2), Hadron>20 MeV fluence and 1 MeV neutron equivalent fluence have been measured. A one week irradiation correspond to 1.0 e18 protons on target, and the hottest area in the TSG45 zone to 3 years of LHC operation (10Gy/year) in the arcs. Most of the equipments installed in LHC tunnel have been tested in CNGS, although the equipment in critical areas need more dedicated tests. Other test facilities have also been used such as PSI [p, 60/250 MeV], CEA [n], UCL [Heavy Ions], NRI [Thermal n], IRA [Co60].

System criticality is analysed in terms of failure consequences, while for equipment sensitivity, assumptions have to be made since a large fraction of LHC electronics is based on industrial equipment for which no reliable data for radiation tolerance exists. The equipment inventory is done by Priority [full list available in talk]:

- Priority 1: Personnel and Machine safety
- Priority 2: Long downtime
- Priority 3: Beam quality degradation
- Priority 4:Monitoring or no immediate impact on the machine

In most cases relocation, shielding, plus partial redesign along with HW/FW modifications. In summary:

- Cryogenics: ok, with soft reset and shielding
- BIC/PIC: ok, shielding and relocation
- BLM: ok
- BPM: ok with mitigation
- QPS: not ok, but with reset of WorldFIP
- CL heaters: not critical, shielding will help
- Survey: ok
- WorldFIP: development of NanoFIP
- Power Converters:some critical

LHC POWER CONVERTERS – THE PROPOSED APPROACH

TE-EPC is confident that LHC60A-08V Power Converter including its digital controller FGC, both originally designed to be rad tolerant, will work adequately for LHC operation purposes. Less than 1 recoverable failure every 3-5 days is expected, when several converters could be lost without losing the beam. Tests under radiation done on digital controller FGC indicated that it could also be compatible with other standard converters installed in critical area like RR point 1, 5, 7, or UJ point 1 and 5. One destructive latch up was encountered only when testing the FGC, considered then as an isolated case.

LHC600A-40V Power Converters being located in UJ76 will be safe thanks to the relocation on-going in TZ76.

Situation on other standard Power Converters is especially unclear and uncertain since Power Part has never been tested under radiations on LHC120A-10V, LHC600A-10V or LHC4..8kA-08V.

- If LHC120A-10V Power Converter is CERN internal design and then can be modified for being more rad-tolerant, other converters are complex external designs.
- Some synergy with Inner Triple Upgrade could be found for the 600A-10V Power Converter in case a redesign is the solution chosen for these Power Converters.
- Case of LHC4..8kA-08V is the most critical, since a redesign is not really feasible.

TE-EPC with help of R2E will organize a Radiation Power Converter Day to better evaluate the current situation:

- Analyzing the components being used in the actual design and trying to quantify the risks
- Checking what to redesign and evaluating partial redesign if possible to limit the redesign work
- Trying to evaluate cost an manpower needs of proposed solution
- Giving the limits of re-location taking in account the Power Converter constraints (In case of relocation, cable losses have to be taken in account to be still compatible with current design)

IS THE WORLDFIP A RELIABLE RAD-HARD FIELDBUS ON LONG TERM?

The WorldFIP fieldbus was chosen to cover communication needs of critical LHC systems needing determinism and radiation tolerance. It is heavily used in LHC with over 450 km of cables, more than 12'000 nodes, and in many critical LHC subsystems such as cryogenics, QPS, Power Converters, beam instrumentation, radio-frequency and Radmon.

WorldFIP slaves use the MicroFIP chip produced by Alstom along with the FielDrive transceiver and associated magnetics. After Alstom announced a progressive decline in support of WorldFIP technology, BE-CO decided to start a technology in-sourcing program in order to guarantee local support of this strategic technology during the lifetime of LHC. The first phase of this program consists in designing an FPGA-based alternative to MicroFIP, called NanoFIP. In addition, the last generation of MicroFIP chips was manufactured using a newer process with reduced feature sizes and there are serious concerns about its radiation tolerance.

The NanoFIP development is therefore now considered a critical part in the global strategy of providing a radiation-tolerant solution to WorldFIP users. A brief overview of the architecture of WorldFIP as presently deployed in the LHC is given in the related paper. Part of the project is to identify the critical devices in terms of radiation tolerance, and show how NanoFIP will provide a solution in the close future. The NanoFIP project is intended for the time being to be ready in 2011.Long-term plans for the overall WorldFIP technology insourcing in BE-CO could also consider as a backup an ASIC version (MicroFIP3) in collaboration with the electronic group of the PH Department.

SUMMARY OF THE 2009 IRRADIATION TESTS AND PERSPECTIVES FOR FUTURE TESTS AND FACILITIES

Most of the electronics systems located in the LHC tunnel and only few systems from the LHC alcoves were tested in the CNGS TSG4 area and in various external facilities in 2009.

The overview of the results from the CNGS campaign was presented and put in contrast to the expected radiation levels in the exposed areas. By applying a best guess scaling of the expected development of the respective LHC radiation levels, failure rates were estimated for both the initial operation in 2010 (assuming 0.5fb^{-1}, 200days of operation and $1/40^{th}$ of nominal losses in the LHC tunnel) and for the nominal operation.

The errors resulting from cumulative effects were translated into the device lifetime estimations. The statistics of the single event errors was translated into the corresponding failure rates taking into account the total number of devices in the critical areas.

Mitigation actions were identified for the systems with too low lifetime or high failure rate. Many systems will profit from the radiation level reduction thanks to the foreseen shielding to extend their lifetime beyond 20 years. Several groups implemented firmware or hardware modifications mostly allowing for automatic resets.

Many systems suffer from the WorldFIP client card errors, which aggravated by at least two orders for the new batch used in the nQPS layer. The mitigation of the SEE induced crashes of the FGC in the power converters should be further studied.

The tests in CNGS TSG4 will continue in 2010 and will include mostly the potentially very sensitive systems from the LHC alcoves. At the same time many test facilities are available outside CERN for component or system tests. If necessary, n_TOF and HiRadMat could provide dedicated electronics test areas, however the respective need would have to be brought forward in the RadWG.

EXPERIENCE WITH THE ATLAS RADIATION TOLERANCE POLICY

ATLAS developed a policy on radiation tolerant electronics, outlined in the document ATC-TE-QA-0001, with the following goals:

- Reliability of the experiment with respect to radiation. The estimated lifetime of components must cover foreseen lifetime of LHC experiments, or at least a large fraction of it
- Mandatory for each sub-system of the experiment
- Coherent approach with the same rules for every sub-systems
- Based on recognized test methods

Including a design/procurement strategy:

- Whenever possible limit electronics in radiation environment
- Radiation tolerant COTS: determine the Radiation Tolerance Criteria (using safety factors when needed), pre-select generic components (radiation tests), purchase batches of pre-selected generic components, qualify batches of components (radiation tests)

Necessary steps to enforce such policy have been defined:

- One dedicated person to the subject, defining a reference point for the designers
- The support of the ATLAS management was mandatory
- Radiation hardness important part of the reviews
- A lot was done to make people aware of the problems with tutorial sessions
- Tools to make sure that the RTC were properly computed
- Organization of common irradiation campaigns (also with RD49)

The policy was discussed and approved by the ATLAS Executive Board. The person in charge of it participated in all the design reviews, bothering people to make sure that tests were properly done. He also followed the work outside the reviews

In case of problems ATLAS was able to ask for additional tests and to block production if necessary (this happened once). Additional tests have very often (not to say always) lead to design changes.

WHERE ARE WE WITH THE LONG-TERM PLANS AND THE CERN-WIDE RADIATION POLICY

The different options for the long term consolidation plan are presented, which should ensure that the risk of SEE in control electronics installed in the LHC is minimized. The plan will imply full (or partly) relocation of the installed electronics for some locations like US85 or UJ56 and UJ76, additional shielding in different areas where relocation is not convenient and may imply major civil engineering for Point 1 and Point 5. The possibility to avoid some of this heavy works by modifying the loss pattern or by redesigning some of the control systems to be radiation tolerant will be summarized for the major systems. Finally, the basic principles to be fixed in a CERN wide radiation policy at CERN will be proposed, with the aim of ensuring that we will never in the future be obliged again to consolidate further exposed underground installations.

In practice the implementation of the policy goes as follows:

- For LHC Machine, the LMC will oversee and give priorities.
- R2E will coordinate technical work at different level and give coherence between simulations, design, test, machine integration.
- RADWG will support equipment groups for design (component selection, design reviews) and radiation test.
- Equipment owners are responsible for implementation and quality assurance.
- Point owners (or persons to be identified) shall be informed of installed equipment and in charge of organizing control. Ensure that OP is aware of the special procedures suggested for a given equipment.

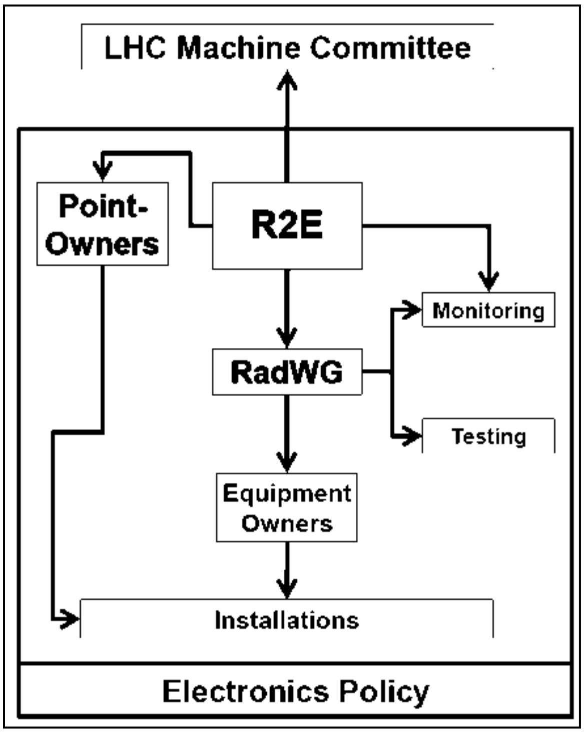

Figure 1: Organisation of the coordination of mitigation efforts in the LHC

There is a relevant risk of occurrence of Single Event Effects in several areas of the LHC machine. A dedicated strategy is required to reduce it to a level that will allow a smooth operation at nominal and ultimate luminosity. Very relevant resources, both in terms of material and of personnel, will be needed to implement it.